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Agricultural Memorandum No. 729

On sugar beet germination

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1. Introduction

As with most Branch Memoranda, this note is to be seen as a discussion paper, and may be read in conjunction with Memorandum No. 701.

It has been pointed out that the analysis for sugar beet germination presented in Memorandum No. 701 does scant justice to the Degree Day summation approach. If, in looking at the temperature versus time relationship, we search for a base temperature which leads to a constant accumulation of Day Degree units over the temperature range under consideration, then for a base of 37°F we obtain the information shown in Table A.

Table A

Temperature accumulations for sugar beet germination.

Constant Temperature °F	Days to 50% emergence	Metabolic Change units/K_b	Degree Days above base 45°F	Degree Days above base 37°F
48	15	15.7	45	165
50	13	14.9	65	169
55	8.5	12.7	85	153
60	7	13.1	105	161
65	6	13.5	120	168
70	5	14.0	125	165
	Mean	14.0	90.8	163.5
	Standard deviation	1.0	28.9	5.3
	Coefficient of variation	7.1	31.8	3.2

2. The relation between (constant) temperature and time to 50% emergence (if soil moisture is never limiting) is not linear. This is demonstrated by the initial data of Fornstrom and Pochop (see Figure 1).

These authors suggest a power law relationship of the form

$$D = 90\ (T-40)^{-0.85}$$

where D = time to 50% emergence (in days)
T = temperature at which experiment took place.
(constant in these studies)

An alternative, exponential relationship is suggested by the data themselves and conventional fitting leads to

$$\ln D = \ln 147 - .0494\ T$$

In the approach of Memorandum 701 the acceptance of a constant Q_{10} value greater than unity implies an exponential response to temperature, and within this overall response, linear approximations to the exponential curve over limited, (10^{o}), intervals were made. (see broken lines Figure 1). The advantage is that calculations may be carried out simply and conveniently without the aid of tables or detailed curve fitting procedures.

In this discussion there are three important considerations

(i) the concept that a constant "energy increment", however defined, is to be associated with a particular developmental phase for biological systems.

(ii) the nature of the temperature/energy increment relationship.

(iii) the data manipulations necessary to transfer constant temperature laboratory findings to the variable temperature field situation.

3.1. Under (i) above, at this point in time, we may simply treat the concept as a convenient working hypothesis that will stand or fall by the results that it achieves.

3.2. In the alternative, or possibly complimentary methods represented by the Day Degree and exponential summations, each procedure operates with a disposable constant - the base temperature on the one hand and the process rate ratio, Q_{10}, on the other in an approach which regards the base or rather the threshold temperature for development as given by the physical observations.

However, there are more implied differences in the approaches than the simple selection of constants.

For all organisms and developmental processes, between lethal or limiting low temperatures on the one hand and lethal or limiting high temperatures on the other, there is some temperature (or temperature range) at which the biological processes proceed at an optimum level. In other words, there is a broad parabolic response to temperature, and the question arises as to the most appropriate expression to fit the parts of this broad temperature/response curve that happen to be of particular concern.

There are two temperature/response relations of immediate interest.

- the first, typical of many biological situations over particular temperature ranges, is a linear response to temperature.

- the second, is an exponential (or power law) response to temperature.

There is ample independent evidence that would suggest that seed germination rate/temperature relationships are commonly of the first kind (ie. show a linear response). In challenging an implied exponential temperature relationship with this biological situation, the area for the argument has been well chosen.

In Figure 2, the observations of temperature and germination rate (I/D = 1/time to emergence) have been fitted by a straight line relationship.

A conventional (least squares) fits gives

$$T + 169\ (I/D) + 36.6$$

An exponential fit to the same data leads to

$$\ln D = \ln 147 - .0494\ T$$

If a linear fit is assumed, we may extrapolate below the lowest temperature at which observations were made (48°F) to arrive at a base temperature (N37°F) at which I/D equals zero, or D is infinite. If for temperatures within the original range of the experiments, Degree Day summations to 50% emergence are calculated, we establish that these are effectively constant. This finding may be generalised, and follows in fact from the initial assumption of a linear relationship.

From Figure 2 we have

$$T = M\ (I/D) + T_b$$

where T = Temperature
T_b = Base Temperature
D = Days to 50% emergence at temperature T
M = slope of line

Simple manipulation indicates

$D\ (T-T_b)$ = Day Degrees accumulated between sowing and 50% emergence.
= M
= constant

The interpretation to be placed on the base temperature T_b is not fixed. In some situations it may be possible to identify the base temperature so obtained with the observed threshold temperature for physical development; in other situations it may not coincide with such a threshold and its use in temperature summations represents simply an alternative statement and assumption of a linear relationship.

3.3. In a study of the transfer of the constant temperature laboratory findings to the variable temperature field situation for seed germination in the spring, it is presumably pertinent to include the case where temperatures fluctuate around the threshold temperature for development. Since an exponential fit to the data does not indicate a convenient threshold temperature, the base temperature derived from a linear fit to the data may be adopted for convenience, in the absence of other information. For the original sugar beet germination data, this implies an extrapolation of some 10°F (from 48°F to 37°F) beyond the lowest observed response. Significant differences in response are implied by the linear and exponential response curves over this temperature range (cf. Figure 2) and it is of interest to consider the outcome predicted by the two response curves on some independent UK data.

Tables 1 to 5 show drilling and (50%) emergence dates for sugar beet, and the daily progress towards emergence when calculations based on soil temperatures at 10 cm (4 ins) follow the linear and exponential relationships shown in Figure 2. The once daily observations of temperature are assumed to represent a mean temperature for the day.

Tables 1 and 2, with late sowings, with soil temperatures always in excess of 37°F and often in excess of 48°F (the temperature of the coolest observation of Figure 1), show that there is little to choose between the two summations. If anything the advantage lies with the exponential relationship.

In Table 3, the advantage lies with the exponential relationship; the temperature mostly lie below 48°F.

In Table 4, where temperatures pass below 37°F for the first time, emergence in 3 weeks is correctly predicted by a summation based on the exponential relationship, in contrast to the 5 week period required by the linear relationship.

Table 5 again demonstrates the advantage of exponential relationship, but its greatest interest lies in the light it throws on soil moisture requirements to break dormancy. The last day with rain, prior to drilling, was 23 March 1971, when 2.1 mm fell. No rain fell over the next 3 weeks and temperature summations begun on the drilling date are obviously misleading. Rainfall of as little as 0.7 mm on 16 April 1971 was sufficient to break dormancy. Temperature summations begun from this date produce a correct prediction of date of emergence.

Discussion

Our objectives should include the synthesis, as much as the analysis, of data, and our concern has to be with simple working solutions.

In this particular instance, once daily field observations of soil temperature are all that are available and the temperature summation based on an exponential fit to the original constant temperature laboratory data, leads to the better result. It could be argued that these observations should be modified to give a more appropriate mean daily value and that the Day Degree summation would then give the more correct prediction. This seems an unnecessary complication.

Several points emerge from this example.

- it is possible to make the transfer from constant temperature laboratory studies to the field situation.
- there are dangers in extrapolating temperature dependent biological relationships beyond the limits of the initial observations.
- that over a temperature range that extends from the lower threshold for development towards the temperature optimum, an exponential relationship is likely to be as informative as the Day Degree approach, and may provide more reliable predictions if the temperatures close to the threshold for development are involved.

- whilst the base temperature obtained from a linear extrapolation observations of development rate (I/D) may in some instances coincide with the physical threshold temperature for development, this coincidence may be fortuitous. A distinction should in general always be drawn between the base temperature for temperature summations and the threshold temperatures for development.

Meteorological Office
Cambridge

April 1975

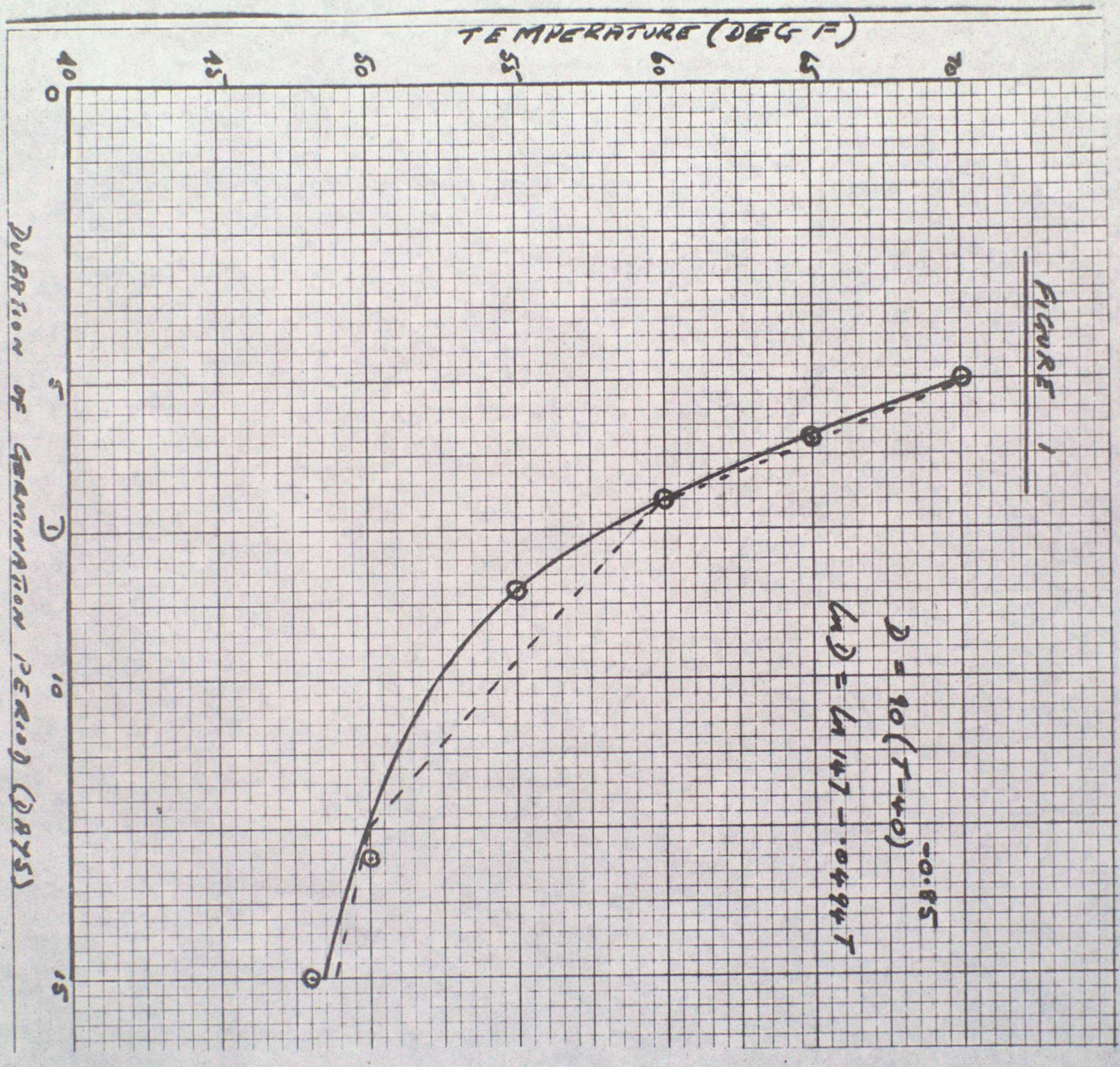
TEMPERATURE (DEG F)
40
45
50
55
60
65
70
0
5
10
15
DURATION OF SUBMINIMUM PERIOD (DAYS)
D = 90 (T-40)^-0.85
ln(D) = ln 147 - .0494 T

FIGURE 1

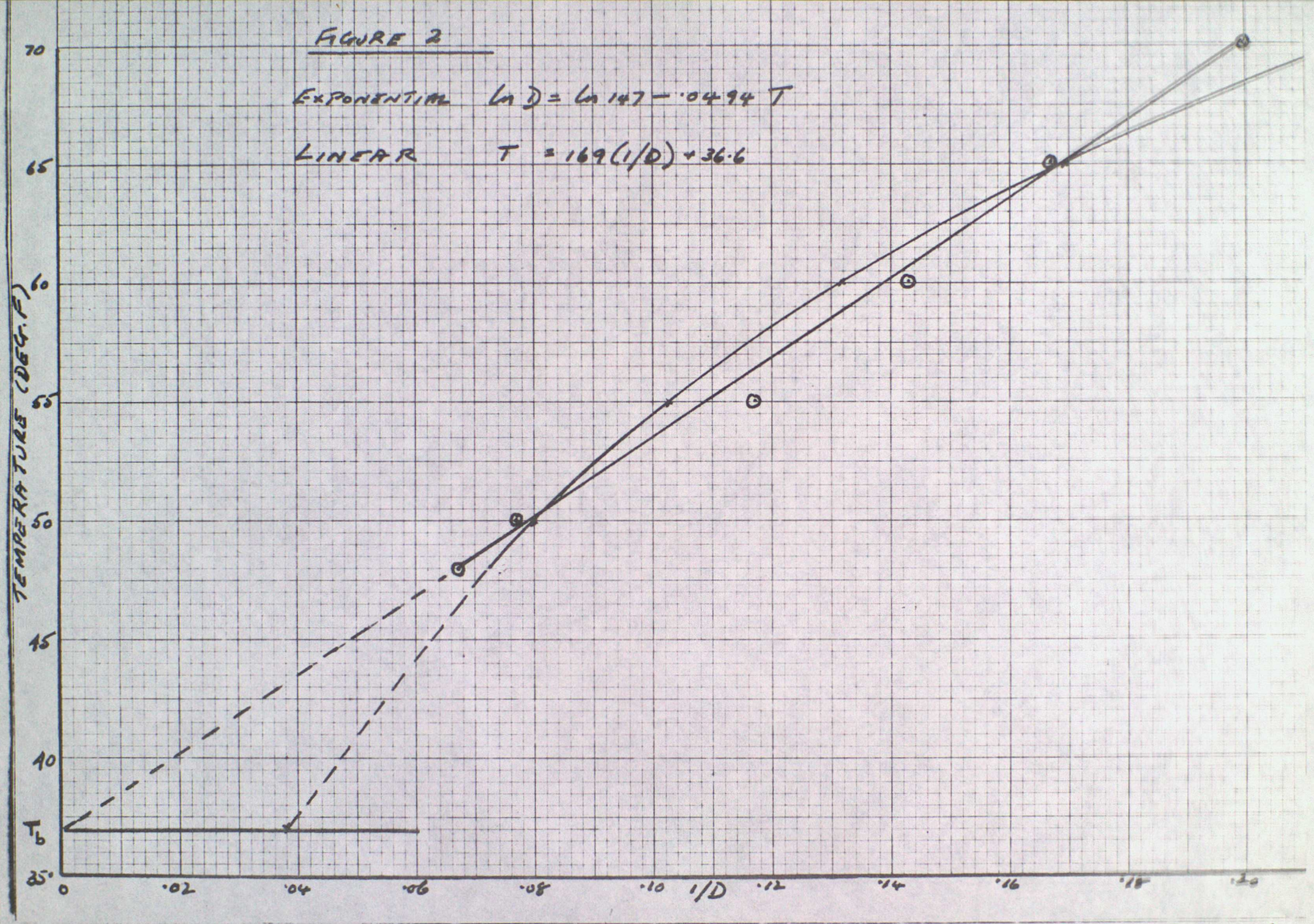
FIGURE 2
EXPONENTIAL Ln D = Ln 147 − ·0494 T
LINEAR T = 169(1/D) + 36·6
TEMPERATURES (DEG. F)
70
65
60
55
50
45
40
T_b
35°
0
·02
·04
·06
·08
·10
1/D
·12
·14
·16
·18
·20

Site Chatteris

Table 1

Date Drilled	Soil Temp. at 10 cm	Daily Development Rate (I/D)	Σ I/D	Day Degrees above 37°F	Σ Day Degrees
20/4/70	42.5°F	.05	.05	5.5	5.5
21/4	51.5	.09	.14	14.5	20.0
22/4	54.5	.10	.24	17.5	37.5
23/4	55.0	.10	.34	18.0	55.5
24/4	42.5	.05	.39	5.5	61.0
25/4	52.0	.09	.48	12.0	73.0
26/4	44.0	.06	.54	7.0	80.0
27/4	40.5	.05	.59	3.5	83.5
28/4	40.0	.05	.64	3.0	86.5
79/4	45.5	.06	.70	8.5	95.0
30/4	45.0	.06	.76	8.5	103.5
1/5	51.5	.09	.85	14.5	118.0
2/5	58.0	.12	.97	21.0	139.0
3/5	57.5	.12	1.0 + 50% Emergence Predicted	20.5	159.5
4/5 Complete Emergence	57.5			20.5	169 + 50% Emergence Predicted
5/5	59				
6/5	59.5				

Site Brampton

Table 2

Date Drilled	Soil Temp. at 10 cm	Daily Development Rate (I/D)	Σ I/D	Day Degrees above 37°F	Σ Day Degrees
24/4/70	44.9°F	.06	.06	7.9	7.9
25/4	48.1	.07	.13	11.1	19.0
26/4	46.3	.07	.20	9.3	28.3
27/4	42.4	.05	.25	5.4	33.7
28/4	40.8	.05	.30	3.8	37.5
29/4	44.1	.06	.36	7.1	44.6
30/4	44.3	.06	.42	7.3	51.9
1/5	47.1	.07	.49	10.1	62.0
2/5	57.2	.09	.58	14.2	76.2
3/5	50.4	.08	.66	13.4	89.6
4/5	53.8	.10	.76	16.8	106.4
Emergence					
5/5	54.6	.10	.86	17.6	124.0
6/5	54.5	.10	.96	17.5	141.5
7/5	55.8		1.0 + 50% Emergence Predicted	18.8	160.3
8/5	57.0			20	169 + 50% Emergence Predicted

Site Brandon Creek

Table 3

Date Drilled	Soil Temp. at 10 cm	Daily Development Rate (I/D)	Σ I/D ($T \geq 37^{\circ}F$)	Day Degrees above $37^{\circ}F$	Σ Day Degrees
8/4/69	$45.1^{\circ}F$	.06	.06	8.1	8.1
9/4	46.7	.07	.13	9.7	17.8
10/4	50.3	.08	.21	13.3	31.1
11/4	50.0	.08	.29	13	44.1
12/4	47.3	.07	.36	10.3	54.4
13/9	42.8	.06	.42	5.8	60.2
14/4	40.6	.05	.47	3.6	63.8
15/4	47.2	.07	.54	10.2	74.0
16/4	43.1	.06	.60	6.1	80.1
17/4	42.3	.06	.66	5.3	85.4
18/4	40.5	.05	.71	3.5	88.9
19/4	40.3	.05	.76	3.3	92.2
20/4	41.9	.05	.81	4.9	97.1
21/4	44.2	.06	.87	7.2	104.3
22/4	45.1	.06	.93	8.1	112.4
23/4	46.0	.07	1.00	9.0	121.4
Emergence			**Emergence predicted**		
24/4	47.0			10.0	131.4
25/4	47.9			10.9	142.3
26/4	50.0			13 0	155.3
27/4	47.2			10.2	165.5
28/4	47.2			10.2	169 +
					Emergence Predicted

Site Brandon Creek

Table 4

Date Drilled	Soil Temp. at 10 cm	Daily Development Rate (I/D)	Σ I/D	Σ I/D ($T \geq 37^{\circ}F$)	Day Degrees above $37^{\circ}F$	Σ Day Degree
24/3/70	$40.6^{\circ}F$	.05	.05	.05	3.6	3.6
25/3	38.3	.05	.10	.10	1.3	4.9
26/3	37.1	.04	.14	.14	0.1	5.0
27/3	36.5	.04	.18	.14	-	5.0
28/3	36.0	.04	.22	.14	-	5.0
29/3	36.1	.04	.26	.14	-	5.0
30/3	40.9	.05	.31	.19	3.9	8.9
31/3	38.6	.05	.36	.24	1.6	10.5
1/4/70	37.0	.04	.40	.28	-	10.5
2/4	35.0	.04	.44	.28	-	10.5
3/4	35.9	.04	.48	.28	-	10.5
4/4	36.7	.04	.52	.28	-	10.5
5/4	37.3	.04	.56	.32	.3	10.8
6/4	40.8	.05	.61	.37	3.8	14.6
7/4	38.3	.05	.66	.42	1.3	15.9
8/4	37.2	.04	.70	.46	0.2	16.1
9/4	37.5	.04	.74	.50	0.5	16.6
10/4	38.2	.05	.79	.55	1.2	17.8
11/4	40.5	.05	.84	.60	3.5	21.3
12/4	41.0	.05	.89	.65	4.0	25.3
13/4	39.9	.05	.94	.70	2.9	28.2
14/4	37.8	.04	.98	.74	0.8	30.0
15/4	45.5	.06	1.04	.80	8.5	38.5
			Emergence Predicted			
16/4	48.8	.07		.87	11.8	50.3
17/4	48.2	.07		.94	11.2	61.5
18/4	49.8	.07		1.01	12.8	74.3
Emergence				Emergence Predicted		
19/4	45.7				8.7	83.0
20/4	42.4				5.4	88.4
21/4	46.0				9.0	97.4
22/4	49.8				12.8	110.2
23/4	49.8				12.8	123.0
					etc	Emergence Predicted 30/4/70 169

Site Little Downham

Table 5

Date Drilled	Soil Temp. at 10 cm	Daily Development Rate (I/D)	Σ I/D	Day Degrees above 37°F	Σ Day Degrees	Daily Rainfall mm	Σ I/D	Σ Day Degrees
8/4/71	43.3	.06	.06	6.3	6.3	tr		
9/4	43.6	.06	.12	6.6	12.9	-		
10/4	43.6	.06	.18	6.6	19.5	-		
11/4	43.2	.06	.24	6.2	25.7	-		
12/4	41.9	.05	.29	4.9	30.6	-		
13/4	47.3	.07	.36	10.3	40.9	-		
14/4	46.8	.07	.43	9.8	50.7	-		
15/4	45.4	.06	.49	8.4	59.1	-		
16/4	44.9	.06	.55	7.9	67.0	0.7	-	-
17/4	42.2	.05	.60	5.2	72.2	-	.05	5.2
18/4	44.8	.06	.66	7.8	80.0	-	.11	13.0
19/4	47.9	.07	.73	10.9	90.9	-	.18	23.9
20/4	49.0	.08	.81	12.0	102.9	-	.26	35.9
21/4	48.5	.07	.88	11.5	114.4	-	.33	47.4
22/4	48.8	.07	.95	11.8	126.2	2.1	.40	59.2
23/4	53.3	.09	1.0 + Emergence Predicted	16.3	142.5	11.9	.49	75.5
24/4	52.9	.10		15.9	158.4	6.1	.59	91.4
25/4	48.0	.07		11.0	169 +	-	.66	102.4
26/4	44.2	.05			7.2		.71	109.6
27/4	41.5	.05		4.5		1.7	.76	114.1
28/4	42.3	.06		5.3		-	.82	119.4
29/4	44.0	.05		7.0		-	.87	126.4
30/4	44.2	.05		7.2		-	.92	133.6
1/5	44.1	.06		7.1		-	.98	140.7
2/5	44.9	.07		7.9		-	1.0 + Emergence Predicted	148.6
Emergence								
3/5	46.2	.06		9.2		-		157.8
4/5	50.0	.08		13.0		-		169 + Emergence Predicted
5/5	50.7			13.7				
6/5	52.7							
7/5	53.0							
8/5								